

Distributional patterns of species diversity of main plant communities along altitudinal gradient in secondary forest region, Guandi Mountain, China

GAO Jun-feng¹, Zhang Yun-xiang²¹ The Key Laboratory for Silviculture and Conservation of Ministry of Education, Beijing Forestry University, Beijing 100083, P. R. China² Forestry College, Shanxi Agriculture University, TaiYuan 030801, P. R. China

Abstract: Fourteen plots were chosen along with the altitude of 1600–2600 m in Guandi Mountain, Shanxi Province, China to investigate all the trees in the plots, and the species diversity indexes were calculated for analyzing the effects of altitudinal gradient on plant species diversity. The results showed that the order of dominant species from low altitude to high altitude is as *Quercus liaotungensis* Koidz, *Pinus tabulaeformis*, *Betula platyphylla*, *B. albo-sinensis*, *Picea wilsonii*, *P. Meyeri* and *Larix principis-rupprechtii*. With altitude increasing, the average height and DBH of the arbor firstly increase and then decrease, the maximal height and DBH of the arbor present the unimodal variable trend, the maximal height of coniferous and broad-leaved trees firstly increases and then decreases, the maximal DBH of broad-leaf trees has no clear fluctuation, and the maximal DBH of the needle-leaf trees decreases gradually. Moreover, in middle altitudinal communities (the altitude of 1900–2200 m), the maximal height and DBH of the needle-leaf trees are larger than these of broad-leaf trees. Both Shannon-wiener index and Margalef index of the communities present the unimodal variable trend, with a peak in the mid-altitude. Plant species diversity in the mid-altitude (1900–2200 m) is higher than that of the low altitude (1600–1900 m) and the high altitude (2200–2600 m). In addition, the unimodal variable trend of α species diversity is clearly correlated with the altitudinal gradient. The change of plant species diversity is significantly correlated with the altitudinal gradient, and also related to the community structure, the community composition, the feature of species and the human disturbance.

Keywords: Species diversity; Altitudinal gradient; Community; Guandi Mountain

CLC number: S717.1

Document code: A

Article ID: 1007-662X(2006)02-0111-05

Introduction

Variable rule of species diversity along with the altitudinal gradient is an important subject of biodiversity research, and is paid more attention by ecologists (Tang 2004). Species diversity reflects species richness and evenness, and expresses differences of community structure, community composition, and community habitat conditions (Lan 2003). The study of species diversity is helpful to understanding community composition, structure, change and development (Li 2002). Moreover, species diversity is affected by multi-environmental factors (Tang 2004; Lan 2003; Li 2002; Gaston 2000) especially by the altitudinal gradient. The change of non-alive condition (e.g. climate, soil and temperature) along with the altitudinal gradient affects species composition and distribution. In a word, the altitudinal gradient is an important factor affecting species composition and structure (Whittaker 1972).

The region in Guandi Mountain, under the control of warm-temperature continental climate, had been strongly disturbed by human activities. The secondary forest occupied the whole region. Some fundamental studies in this region focus on *Quercus liaotungensis* communities (Gao 1998; Wu 2004) and some deciduous broad-leaved forests (Gao 2001; Xie 1994). Furthermore, Tang *et al.* (2004) studied the plant species diversity along the altitudinal gradient on Qinling Mountains (Tang 2004) and Liu *et al.* (2004) reported the changes in plant species

diversity along an elevation gradient on Xiaowutai Mountain (Hebei Province). The relationship between species diversity and the altitudinal gradients has been discussed with α and β diversity indexes. In this study, the community species composition, species diversity and the community structure along the altitudinal gradients on Guandi Mountain were investigated. At the same time, the variable trend of species diversity and the dynamic of the environmental influence on species diversity were analyzed and discussed. The result can provide significant reference for forest protection and utilization of this region.

Materials and methods

Study site

The study was conducted in Guandishan Pangquangou Nature Reserve in Guandi Mountain which is located in the middle range of LuLiang Mountain in Shanxi Province (37°20′–38°20′S, 110°18′–111°18′E). This region has warm-temperature continental climate. The average annual temperature is 3–4 °C. Mean annual precipitation is in range of 600–800 mm, and 60% of the precipitation concentrates in July to September. Soil types include light brown soil, mountain eluviated brown soil, mountain brown soil and sub-alpine meadow soil. The regional forest possesses the typical vegetation in horizontal distribution belts, including (from low altitude to high one) deciduous broad-leaved forest (the local vegetation), coniferous and broad-leaved mixed forest, and coniferous forest. Main forest types are *Larix principis-rupprechtii* forest, *Picea wilsonii* forest, *P. meyer* forest, *Pinus tabulaeformis* forest, *Populus davidiana* forest, *Betula platyphylla* forest and *B. albo-sinensis* forest, *Quercus liaotungensis* Koidz forest.

Shrub species include *Lonicera chrysantha*, *Spiraea pubescens*, *Rosa daburic*, *R. bella*, *Ribes mandshuricum*, *Rubus idaeus*,

Foundation item: This paper was supported by Shanxi Natural Science Foundation (20001090).

Biography: GAO Jun-feng (1979-), male, Ph.D. Candidate, Beijing Forestry University, Beijing 10083, P. R. China. Email: fengjigao@126.com.

Received date: 2005-09-16

Accepted date: 2005-12-25

Responsible editor: Zhu Hong

Berberis amurensis, *Potentilla glabra*, etc..

Grass species include *Carex lanceolata*, *Phlomis umbrosa* Turcz., *Thalictrum petaloideum*, *Artemisia* Spp., *Poa* Spp., *Maianthemum bifolium* L., *P. odoratum* Cmill Druce, *P. Sibiricum* Delar. Ex Red, *A. simthii* ulbr. exhand-Mazz, *Vicia amoena* Fisch, etc..

Methods

During August to September in 2004, 14 plots were chosen in the study area along with the altitude of 1600–2600 m, and were simply divided into 3 parts according to the altitudinal gradient, at intervals of 300 m. In each plot of 20 m×30 m, the altitude, aspect, slope and position were recorded. And the species, number, height and DBH (diameter at breast height) were investigated and recorded for all the trees (height>5 m, DBH>2 cm). Each plot was divided into six subplots (10 m×10 m) and the species, number and coverage of shrubs (height<5 m, DBH<2

cm) were recorded in each subplot. All the informations of 14 sample polts were given in Table 1. Moreover, the species, abundance and coverage were also investigated for herbs. Shannon-wiener and Margalef indexes were used to estimate a species diversity of the communities.

$$H = 3.3219 \left(\lg N - 1/N \sum_{i=1}^S n_i \lg n_i \right) \quad (\text{Shannon 1949})$$

$$R = S - 1/\ln N \quad (\text{Margalef 1957})$$

where, H is the value of species diversity in a community composed of S species, N the number of species in the total community, and n_i the number belonging to the i th category (Shannon 1949).

Table 1. General situation of the sites

Plot	Site	Community type	Altitude (m)	Area (m ²)	Average height (m)	Average DBH (cm)	Maximal height (m)	Maximal DBH (cm)	Shannon index	Margalef index
P1	Haojia ditch	<i>Q. liaotungensis</i> Koidz.	1650	600	6.3	7.3	13.2	12.1	2.20	4.92
P2	Haojia ditch	<i>P. tabulaeformis</i> + <i>Q. liaotungensis</i> Koidz.	1718	600	7.7	9.8	15.7	14.5	2.30	5.54
P3	Huihui ditch	<i>P. tabulaeformis</i>	1870	600	4.7	11.4	18.7	18.7	2.15	6.21
P4	Huihui ditch	<i>B. albo-sinensis</i> + <i>P. tabulaeformis</i>	1880	600	6.9	10.1	19.3	19.7	2.49	5.96
P5	Haojia ditch	<i>Q. liaotungensis</i> Koidz+ <i>P. tabulaeformis</i>	1890	600	10.9	12.7	16.6	20.9	2.42	6.19
P6	Huihui ditch	<i>P. tabulaeformis</i> + <i>B. albo-sinensis</i>	1920	600	7.3	8.9	17.2	19.2	2.41	6.47
P7	Badao ditch	<i>B. albo-sinensis</i> + <i>L. principis-rupprechtii</i>	1930	600	10.7	12.0	19.7	19.0	2.35	6.00
P8	Haojia ditch	<i>B. platyphylla</i> + <i>B. albo-sinensis</i>	2018	600	8.7	9.8	17.7	19.0	2.40	6.21
P9	Water shed	<i>L. principis-rupprechtii</i> + <i>B. albo-sinensis</i>	2080	600	15.6	14.4	19.4	23.6	2.51	6.00
P10	Water shed	<i>B. albo-sinensis</i> + <i>P. Wilsonii</i>	2125	600	13.8	14.1	22.5	14.5	2.10	5.80
P11	Water shed	<i>P. Wilsonii</i> + <i>B. albo-sinensis</i>	2220	600	11.0	12.3	17.4	23.0	2.25	5.70
P12	YangJuan ditch	<i>P. Wilsonii</i> + <i>L. principis-rupprechtii</i>	2390	600	9.8	10.5	18.7	15.4	2.20	5.22
P13	Xita ditch	<i>P. Wilsonii</i>	2470	600	8.2	8.2	19.4	13.2	1.82	5.00
P14	Peak	<i>L. principis-rupprechtii</i>	2650	600	3.7	9.7	9.7	10.3	1.99	5.30

Results

Species composition

With the altitude increasing, needle-leaf trees replace broad-leaf trees and become dominant trees in communities, the number of shrubs under trees declines and finally disappears, and the durable-shade herbs appear. Community structure and composition are simplified, especially in coniferous forests near high altitudinal areas (Table 2).

Change of tree height and DBH along the altitudinal gradient

With the altitude increasing, the average height and DBH of the trees firstly increase and then decline (Fig. 1, 2). The maximum average height and DBH of the trees were found in the altitude of 2000–2200 m. The order of average height and DBH along different altitudinal gradient is as follows: middle altitude > low altitude > high altitude. *Quercus liaotungensis* Koidz and *Pinus tabulaeformis* live in low altitudinal communities with strong human disturbances (the altitude of 1600–1900 m). *Betula platyphylla*, *B. albo-sinensis* and *Larix principis-rupprechtii*

inhabit the middle altitudinal communities with relatively little human disturbances (the altitude of 1900–2200 m). These pioneer trees with a maximum average height and DBH have advantages over *Quercus liaotungensis* Koidz and *Pinus tabulaeformis* in fast growth, in full fruitages and strong adaptive abilities. Moreover, the average height and DBH for the conifers (*Larix principis-rupprechtii*) in high altitude (2200–2600 m) are minimal, because of the rigorous condition, especially the strong wind.

With the altitude increasing, the maximal height and DBH of trees firstly increase and then decrease, with a peak in the communities at the altitude of 1900–2200 m, (Fig. 3, 4; $R^2=0.7008$, $R^2=0.6641$, $P<0.01$). In the low altitudinal communities, human disturbances are chief factors affecting growths of trees, and impair advantages of water and heat. In the middle altitudinal communities, the quantities of water and heat are adequate and human disturbances lessen obviously, thus the maximal height and DBH of trees are maximal in the communities. In contrast, the maximal height and DBH of trees in the high altitudinal communities are minimal because of rigorous environmental conditions.

In a word, the changes of the tree height and DBH are related

to the altitude, community composition, and the feature of trees

as well as human disturbances.

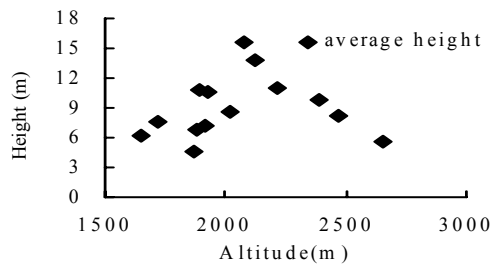


Fig. 1 Changes of average height of the trees

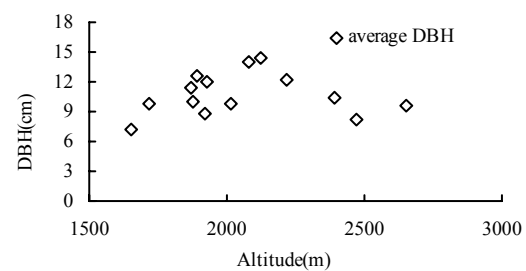


Fig. 2 Changes of average DBH of the trees

Table 2. Species composition in the sites

Plots	Altitude(m)	Community types	Main species composition	
P1	1650	<i>Q. liaotungensis</i> Koidz.	Tree	<i>Q.liaotungensis</i> Koidz.
			Shrub	<i>C. mandshurica</i> Maxim, <i>R. davurica</i>
			Herb	<i>T. alpinum</i> , <i>P.chinensis</i> Ser, <i>Peucedanum terebinthaceum</i> Fisch ex Turcz
P2	1718	<i>P. tabulaeformis</i> + <i>Q. liaotungensis</i> Koidz.	Tree	<i>P.tabulaeformis</i> , <i>Q.liaotungensis</i> Koidz.
			Shrub	<i>C. mandshurica</i> Maxim, <i>R.davurica</i>
			Herb	<i>Podoratum</i> , <i>C.intricata</i> Bge, <i>Veratrum nigrum</i>
P3	1870	<i>P. tabulaeformis</i>	Tree	<i>P.tabulaeformis</i>
			Shrub	<i>C. mandshurica</i> Maxim, <i>V. schensianum</i> Maxim
			Herb	<i>T. alpinum</i> , <i>P.umbrosa</i> , <i>Plantago asiatica</i> L., <i>Dendranthema chanaatii</i> Levl shih
P4	1880	<i>B.albo-sinensis</i> + <i>P.tabulaeformis</i>	Tree	<i>B.albo-sinensis</i> , <i>P.tabulaeformis</i>
			Shrub	<i>C. mandshurica</i> Maxim, <i>S.pubescens</i>
			Herb	<i>P.umbros</i> , <i>Carex. lanceolata</i> , <i>T. alpinum</i> , <i>Dendranthema chanaatii</i> Levl shi,
P5	1890	<i>Q. liaotungensis</i> Koidz+ <i>P. tabulaeformis</i>	Tree	<i>Q.liaotungensis</i> Koidz, <i>P.tabulaeformis</i>
			Shrub	<i>L. chrysantha</i> , <i>S.pubescens</i>
			Herb	<i>Peucedanum terebinthaceum</i> Fisch ex Turcz, <i>Plantago asiatica</i> L., <i>T. alpinum</i>
P6	1920	<i>P. tabulaeformi</i> + <i>B. albo-sinensis</i>	Tree	<i>P.tabulaeformi</i> , <i>B.albo-sinensis</i>
			Shrub	<i>Lespedeza bicolor</i> , <i>S.pubescens</i> , <i>C. mandshurica</i> Maxim
			Herb	<i>Plantago asiatica</i> L., <i>Dendranthema chanaatii</i> Levl shih, <i>T. alpinum</i> , <i>A.smithii</i>
P7	1930	<i>B. albo-sinensis</i> + <i>L. principis-rupprechtii</i>	Tree	<i>B.albo-sinensis</i> , <i>L.principis-rupprechtii</i>
			Shrub	<i>C. acutifolius</i> , <i>R.davurica</i> , <i>S.pubescens</i>
			Herb	<i>T. alpinum</i> , <i>Equisetum pratense</i> , <i>Polygonum ariculare</i> L.
P8	2018	<i>B.platyphylla</i> + <i>B.albo-sinensis</i>	Tree	<i>B.platyphylla</i> , <i>B.albo-sinensis</i>
			Shrub	<i>L. chrysantha</i> , <i>C. mandshurica</i> Maxim, <i>Lespedeza bicolor</i>
			Herb	<i>P.umbrosa</i> , <i>P.sibiricum</i> , <i>V. amoena</i> , <i>Equisetum pratense</i>
P9	2080	<i>L. principis-rupprechtii</i> + <i>B. albo-sinensis</i>	Tree	<i>L.principis-rupprechtii</i> , <i>B.albo-sinensis</i>
			Shrub	<i>C. acutifolius</i> , <i>R.davurica</i>
			Herb	<i>T. alpinum</i> , <i>Bupleurum Chinese</i> Dc, <i>G.verum</i> L
P10	2125	<i>B. albo-sinensis</i> + <i>P. Wilsonii</i>	Tree	<i>B.albo-sinensis</i> , <i>P.Wilsonii</i>
			Shrub	<i>C. acutifolius</i> , <i>R. davurica</i>
			Herb	<i>Equisetum pratense</i> , <i>T. alpinum</i> , <i>Carex. lanceolata</i>
P11	2220	<i>P. Wilsonii</i> + <i>B. albo-sinensis</i>	Tree	<i>P.Wilsonii</i> , <i>B.albo-sinensis</i>
			Shrub	<i>C. acutifolius</i> , <i>S.pubescens</i>
			Herb	<i>T. alpinum</i> , <i>Equisetum pratense</i> , <i>Polygonum ariculare</i> L.
P12	2390	<i>P. Wilsonii</i> + <i>L. principis-rupprechtii</i>	Tree	<i>P.Wilsonii</i> , <i>L.principis-rupprechtii</i>
			Shrub	<i>V. schensianum</i> Maxim, <i>C. acutifolius</i> , <i>L. chrysantha</i>
			Herb	<i>T. alpinum</i> , <i>Polygonum ariculare</i> L, <i>Podoratum</i> , <i>Maianthemum bifolium</i>
P13	2470	<i>P. Wilsonii</i>	Tree	<i>P.Wilsonii</i>
			Shrub	<i>C. Acutifolius</i> , <i>L. chrysantha</i>
			Herb	<i>Podoratum</i> , <i>P.umbros</i> , <i>Carex. lanceolata</i>
P14	2650	<i>L. principis-rupprechtii</i>	Tree	<i>L.principis-rupprechtii</i>
			Shrub	Absence
			Herb	<i>Carex. lanceolata</i> , <i>Equisetum pratense</i>

Change of the height and DBH in different life types of trees with the altitudinal change

Along with the increasing altitude, the max-heights of coniferous and broad-leaved trees firstly increase and then decrease, but, the max-DBH of broad-leaved trees is out of the unimodal trend, which reduces continuously. These changes may reflect the alteration of dominant trees in the community (Fig. 5, 6;

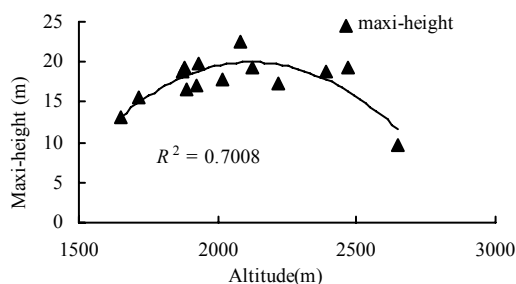


Fig. 3 Changes of maximal height of the trees along with the altitudinal gradient

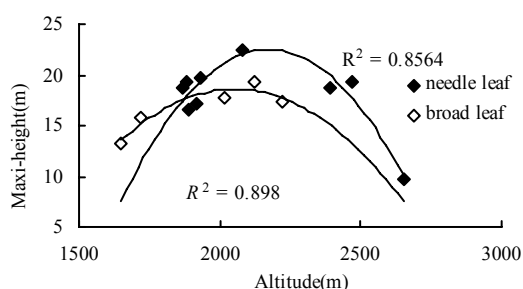


Fig. 5 Changes of maximal height in different life types of trees

Changes of α species diversity along altitudinal change in Shannon-wiener index

With the increasing altitude, Shannon-wiener index presents unimodal variable trend (Fig. 7; $R^2=0.6070$, $P<0.01$). The maximum is 2.51 and the minimum is 1.82. The order of Shannon-wiener index in different altitudes is as follows: middle altitude (1900–2200 m) > low altitude (1600–1900 m) > high altitude (2200–2600 m). In low altitudinal communities, Shannon-wiener index fluctuates from 2.2 to 2.4, and the main species include pioneer trees, shrubs (e.g. *Spiraea pubescens*, *C. acutifolius*, *Lespedeza bicolor*) and herds that like sunshine (e.g. *Plantago asiatica* L., *Gverum* L., *Polygonum ariculare* L.). Moreover, in middle altitudinal communities, Shannon-wiener index reaches 2.51, the community species diversity index reaches a maximum, and the durable-shade trees (*P. wilsonii*, *P. meyeri*) and herds appear, such as *P. umbrosa*, *P. odoratum*, *Maianthemum bifolium*, *Carex. Lanceolata*. In high altitudinal communities, the species is simple, and Shannon-wiener index is minimal (1.82).

The relation between community species diversity and the altitude was analyzed via Spss11.0 software (Table 3). In addition, the phenomenon that species diversity reaches the maximum in

$R^2=0.8564$, $R^2=0.8980$, $P<0.01$).

The height and DBH of the coniferous trees are bigger than that of the broad-leaved trees in the middle altitude. From the low altitude to the high altitude, the order of the dominant trees is as follows: *Q. liaotungensis* Koidz, *P. tabulaeformis*, *B. albo-sinensis*, *B. platyphylla*, *Larix principis-rupprechtii*, *P. wilsonii* and *P. meyeri*.

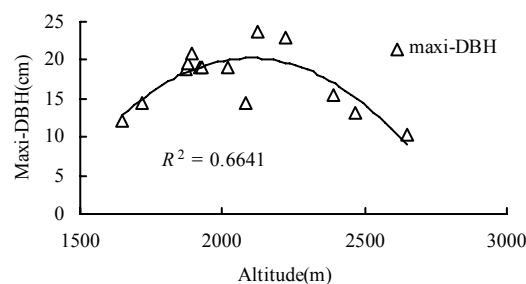


Fig. 4 Changes of maximal DBH of the trees along with the altitudinal gradient

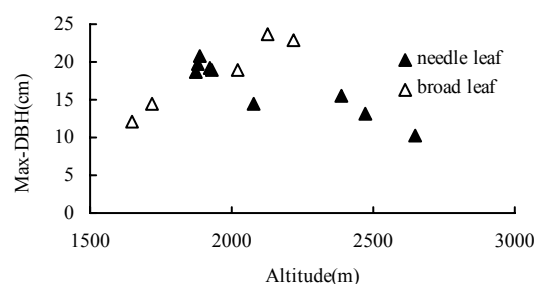


Fig. 6 Changes of maximal DBH in different life types of trees

the middle altitude is consistent with immediate disturbance hypothesis (IDH).

Changes of Margalef index along with the altitudinal gradient

With the altitude increasing, Margalef index presents the same fluctuation with Shannon-wiener index. The maximum is 6.47 in the middle altitude and the minimum is 5.0 in the low altitude. The variety of species diversity showed unimodal trend (Fig. 8; $R^2=0.9245$, $P<0.01$). These results all indicate that middle altitudinal communities possess rich species diversity and that conditions of water and heat are main limiting factors along with the altitudinal gradient in this research region.

Table 3. Result of the correlation

Factors	Average Height	Average DBH	Maximal Height	Maximal DBH	Shannon Index	Margalef Index
Altitude	0.105	0.044	-0.128	-0.260	-0.600*	-0.373

Note: $P<0.05$; *---- Correlation is significant at the 0.05 levels.

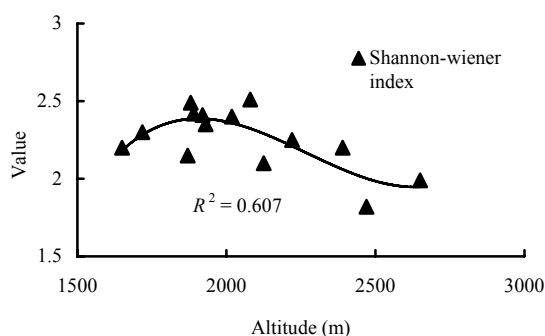


Fig. 7 Changes of Shannon-wiener index along with altitudinal gradient

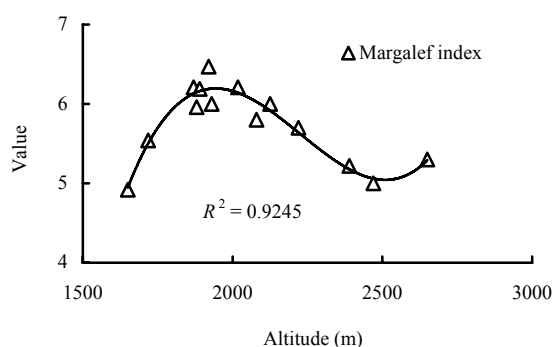


Fig. 8 Changes of Shannon-wiener index along with altitudinal gradient

Conclusions and suggestion

In this region, with the increasing of altitude, the average tree height and DBH firstly increase and then decrease. The tree max-height and DBH also have the same variable trend, and reach a maximum in middle altitudinal communities (the altitude of 1900–2200 m). The change in max-heights of different life types also reflects unimodal trend. The max-DBH of needle-leaf trees has no clear fluctuation. The max-DBH of broad-leaf trees reduces continuously. In middle altitudinal communities, the max-height and DBH of coniferous trees are larger than those of broad-leaved trees. On the other hand, along with the increasing altitude, species composition and structure in the community clearly change. These changes are related to conditions of water, heat and biological, ecological characters of the species.

In the altitude of 1600–2600 m, α species diversity (Shannon-wiener and Margalef index) firstly increases and then decreases. The plant species diversity of the middle altitude (1900–2200 m) is higher than that of low altitude (1600–1900 m) and the high altitude (2200–2600 m). Plant species diversity and distribution are obviously related to the altitude, and is consistent with immediate disturbance hypothesis (IDH).

The effect of the altitude on plant species diversity has been studied in many regions, especially in warm-temperature continental climate region. The unimodal model has become general

model describing this effect. In this paper, our result also agrees with the results of Tang *et al.* (2004), Lan (2003); Li *et al.* (2002). Although the major results of these articles in similar climates proved this model, some ecologists still found some contrary patterns and phenomena. For example, in the Mediterranean region, Montalvo (1993) found that species diversity declined at all time along with the increasing altitude, and species category decreased from 134 to 43. However, in the Canadian mountainous region, Lee (1979) found the contrary phenomena compared with Montalvo's study that species category increased along with the altitude. In a word, the variable trend of species diversity affected by the altitude is obviously related to environmental conditions (climate, soil, rainfall and so on). So far, many ecologists have accepted the unimodal model and IDH, but this model needs yet to be discussed and researched in different regions for protecting and managing species diversity further.

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